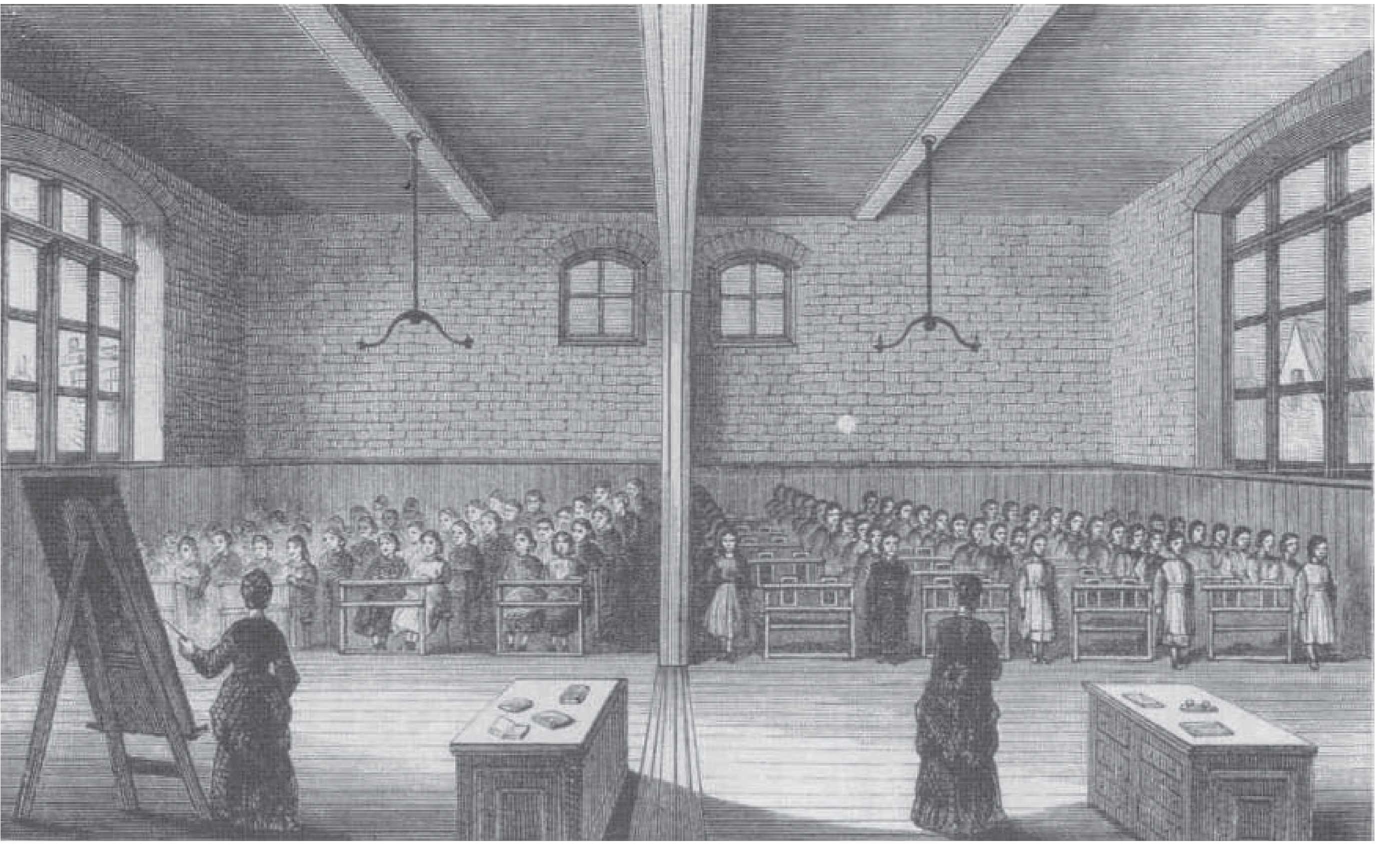
National Institute of BUILDING SCIENCES

National Clearinghouse for Educational Facilities

A History of School Design and its Indoor Environmental Standards, 1900 to Today



Lindsay Baker
PhD Candidate, Department of Architecture
Center for the Built Environment, UC Berkeley

January 2012

National Clearinghouse for Educational Facilities
a program of the National Institute of Building Sciences
1090 Vermont Avenue, N.W., Suite 700, Washington, DC 20005-4950
888-552-0624 www.ncef.org

An Authoritative Source of Innovative Solutions for the Built Environment

Table of Contents

1 Introduction 3

2 "Safety, Permanence and Endurance"- School Building Prior to 1930 4

2.1 Evaluation and Standards 5
2.1.1 Ventilation, Heating and Air Quality 6
2.1.2 Lighting 6

3 The Progressive Era (1930-1945) 8

4 Post-war boom (1945-1960) 9
4.1 Evaluation & standards 11
4.1.1 Ventilation, Heating and Air Quality 11
4.1.2 Lighting 13
4.1.3 Acoustics 15

5 The "Impulsive" Period (1960-1980) 16
5.1 Energy consumption trends 17
5.2 Evaluation and standards 17
5.2.1 Ventilation, Heating andAir Quality 17
5.2.2 Lighting 18
5.2.3 Acoustics 19

6 Declines of the 1980s and the New Movements of the 1990s and 2000s 20
6.1 Energy consumption trends 21
6.2 Evaluation and standards 21
6.2.1 Ventilation, Heating and Air Quality 21
6.2.2 Lighting 22
6.2.3 Acoustics 22

7 21st Century School Environments: What does the future hold? 23

8 Conclusion 24

9 Works Cited 25

Questions for the author? Email her at lindsay_baker@berkeley.edu

1 | Introduction

Public education is one of the central tasks of a democratic society, and the buildings that house this important task not only shape the way we teach, but provide icons and symbols for the values we hold common as a society. Perhaps unsurprisingly, this context has placed school buildings squarely in a position of debate and innovation since our nation began, and school buildings continue to be the subject of careful study and debate today. Schools are influenced by political and social movements, new technologies and trends, the growing awareness of what makes us learn better and thus our notions of what makes a great school are constantly shifting and adapting to new ideas. Yet, we are still surrounded by the schools that matched the ideologies of over a century ago, when the world and our understanding of education was quite different; we lit buildings with the sun, we heated with massive oil and coal furnaces, and children were to be seen and not heard. How have we followed this path to our current day school buildings, and what inspired the differences we see today in school buildings built in the past century? We are lucky to have well-documented sources to help us understand this evolution, as school buildings have long been carefully considered by scholars. What follows is a brief history of the past century and a half of school design, focusing particularly on the systems that made our schools livable and conducive to learning: lighting, heating, cooling, ventilation, and acoustics.

The history of school construction is one of careful research, standardization and calculated design.

Indeed, as one professor of architecture at Columbia University in 1910 noted, "The data for the designing of public school buildings have been more completely standardized than for any other type of structure, except the American public library"(Hamlin, 1910, p. 3). School researchers and standard-setters were passionate about providing adequate school facilities for education, not only for the sake of housing learning (which was not seen as a particularly delicate task until the 1930s), but for the sake of building lasting icons of our culture, and for the communities that schools served. Another author at the turn of the century noted the values that should guide school design, saying, "[t]he school building should be simple, dignified and plain and should be built of the most enduring materials procurable; first, because this contributes to safety, permanence and endurance, and second, because the true character of the building will be best expressed through such materials"(Mills, 1915, p. 34). In the decades that would follow, those writing about school facilities would speak with similar passion and assurance that schools needed to follow quite different principles, from the need to be open to the air, to the need to be quickly built, and to the need to provide space for multiple modes of instruction. All of these movements were accompanied by research studies, pilot school projects and avid supporters.

As we move forward in our new century of school building in the U.S., it is instructive to look back at the trends and designs of the recent past, to reflect on ideas that never quite caught on, to investigate theories that didn't hold up well in practice, and to ultimately evaluate the true implications of today's trends in school design.

2 | "Safety, Permanence and Endurance"- School Building Prior to 1930

Prior to the turn of the century, considerable scholarship and writing was devoted to the need for standard school buildings, in a departure from the early American years of the one-room schoolhouse. As cities and towns became more populous and greater attention was focused on establishing the proper infrastructure for a growing society, school buildings became a new project for societal reformers. One early scholar described early school buildings as, "almost universally, badly located, exposed to the noise, dust and danger of the highway, unattractive, if not positively repulsive in their external and internal experience" (Barnard, 1842, as quoted in Weisser, 2006). An early model for the standard adequate classroom was drawn up by Horace Mann, an early educational reformer, which called for standard rows of desks, windows on two sides of the room, and a variety of other necessary amenities (see Figure 1). It was this movement, known as the Common School movement, which popularized the notion of free schools paid for by local property taxes, which grew over time in the first half of the 19th century across the country. In one key moment for public education, the Kalamazoo Decision of 1874 determined that public schools paid for by local property taxes were legal, which allowed for the vast expansion of public schools in the coming decades (ibid).

These early attempts at standard school design may have helped address the problem of standardizing school buildings, but ultimately this became a necessity as cities and towns were faced with increasing enrollment and responsibility for educating students as the 19th century progressed. As child labor laws became more commonplace, the Civil War ended, and the nation was thrust into the Industrial Revolution. This meant that more children were expected to attend schools, especially in cities, and schools were built and added onto in a fashion that would later have them labeled as "factory-like, dark and dank", or, as Tanner and Lackney tell of this trend, "[f]actories created to produce things led to factories to produce learning" (Tanner & Lackney, 2005; Weisser, 2006). Tanner and Lackney note that over 200 school buildings were built in New York City in the 1920s alone.

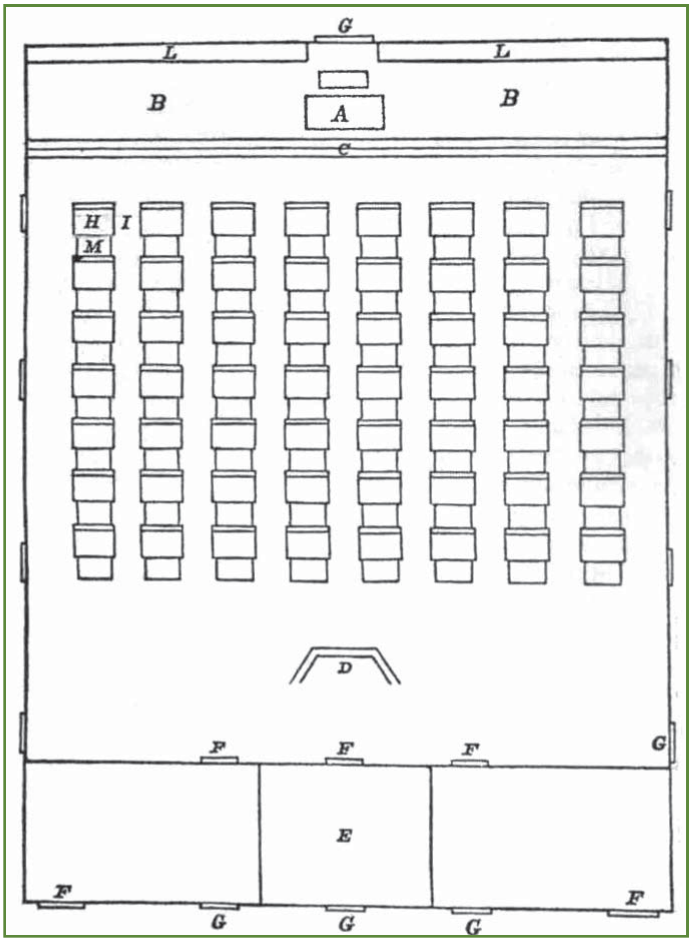


Figure 1. Horace Mann's plan for the one-room schoolhouse, 1938, from Weisser 2006

Schools built during the last decades of the 19th century and early decades of the 20th century were therefore largely standardized, utilitarian spaces that were designed to house as many students as possible, maximizing classroom space (as is noted by a drawing from England in Figure 2 representing an ideal layout under this philosophy). While they could be quite elegant

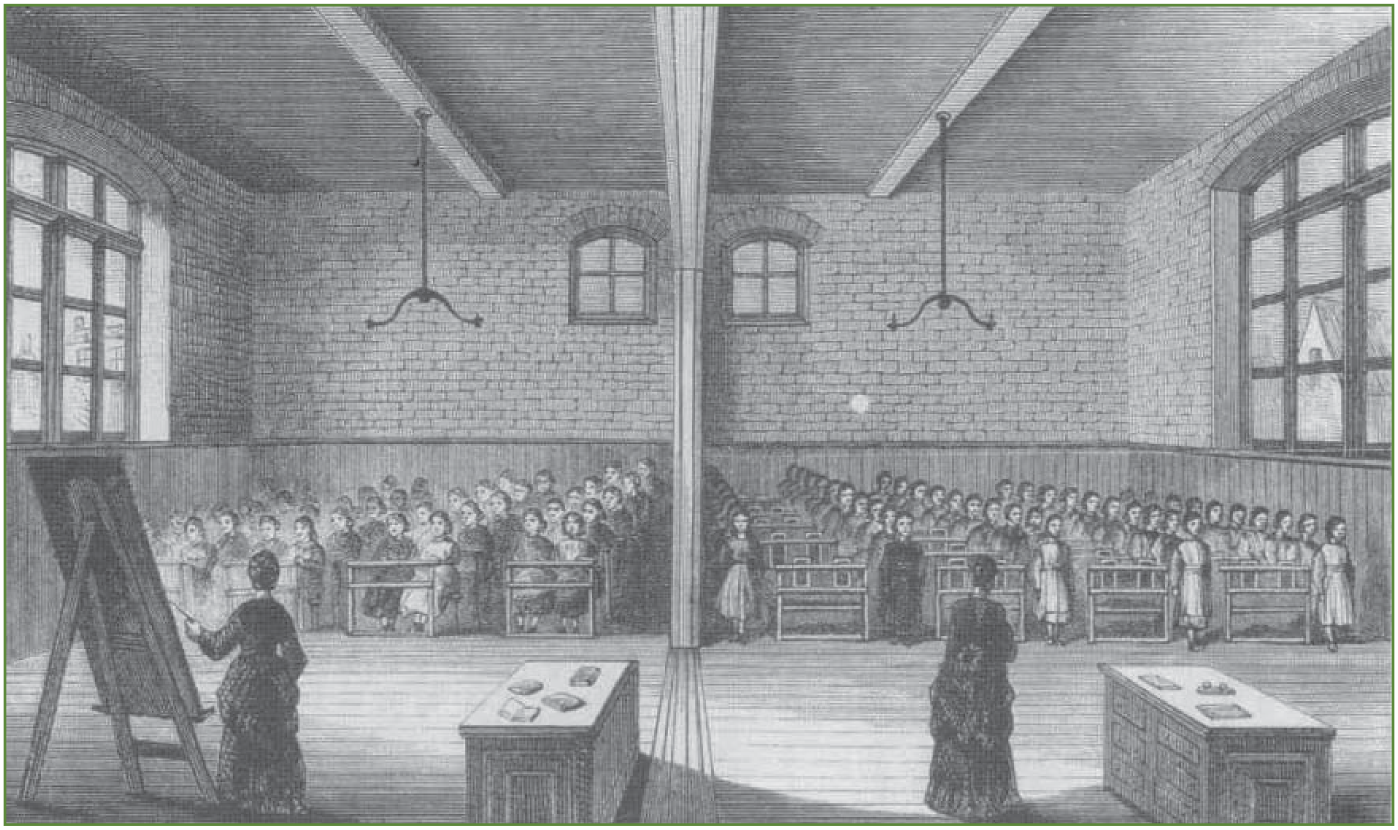


Figure 2. From Dudek, 2000, this drawing represents more of a British ideal classroom layout from the turn of the century, originally from the book School Architecture by E.R. Robson.

buildings, they were just as often crowded and impersonal. One example of this era can be seen in Figure 3, in the Bridgeport High School in Connecticut. As Weisser notes, school façade styles were quite traditional, and generally reflected the Beaux-Arts form, Colonial Revival, Gothic, and other neo-classical styles that were popular at that time.

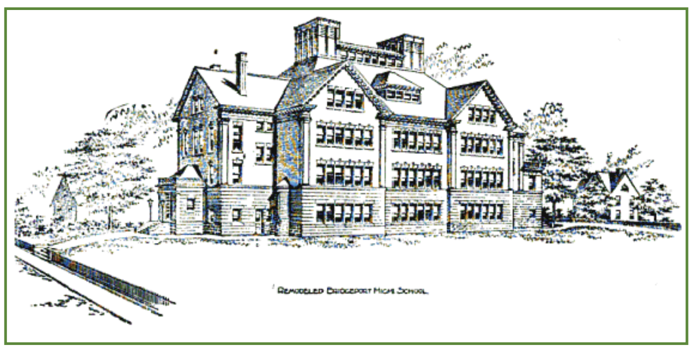


Figure 3. Bridgeport High School in Connecticut, as of 1879, from Modern American School Buildings, Briggs, 1899

2.1 Evaluation and Standards

Around the turn of the century, many books were written on the appropriate design and construction of school buildings, in which environmental systems are covered in depth (Briggs, 1899; Hamlin, 1910; Mills, 1915). Although many of these texts focus heavily on plans and layout suggestions, there was a great deal of attention paid to the proper lighting and ventilation of classrooms and schools as a whole. Indeed, one text (Hamlin, 1910) includes three separate articles on heating and ventilation for different school contexts: “Exposed Localities”, “Congested City Districts”, and “Inexpensive Schoolhouses”. During this time, there was less mention of the principles of acoustical design and control, except a brief reference to the importance of choosing flooring materials and other related finishes to reduce footfall noise.

2.1.1 Ventilation, Heating and Air Quality

Good ventilation was of fundamental importance to school designers at the turn of the century, and new systems for the purpose of ventilating and heating schools and classrooms were rapidly emerging on the market, using many different techniques. Though school ventilation and its systems were still in their infancy, the authors publishing on the subject at the time speak with confidence and clarity, as is typified by this statement by Briggs: "I believe there is not the slightest difficulty in heating and ventilating any school building in a perfectly satisfactory manner by a simple, comparatively inexpensive, automatic system which is easily handled and maintained, and that as a rule the less complicated the apparatus is the better the results obtained from it will be" (Briggs, 1899, p. 170). Today's practitioners may find this confidence surprising, but one must remember that it is merely in comparison to past methods of heating and ventilating that Briggs feels so confident.

In its simplest form, instructions for the heating and ventilating of classrooms could be boiled down to this statement from Hamlin in 1910: "Abundant quantities of warmed fresh air should be introduced through ducts to each schoolroom, and care must be taken that the ducts are of sufficient area and directness for passing the required amount. Ducts should also be provided for removing the vitiated air" (p. 8). Even at this point, however, more stringent requirements were already in place, and had been implemented locally as early as the last years of the 19th century. Although standards were not universal across all states, Mills notes that there was general agreement, saying "[i]n Massachusetts the state law requires that the ventilating apparatus of all school buildings shall supply at least 30 cubic feet of fresh air per minute.... This has practically become the standard the country over" (Mills, 1915, p. 98). Another writer echoes this sentiment, saying, "It is universally agreed that the fundamental requirement for the ventilation of all classrooms and assembly rooms is the supply of 30 cubic feet (or a trifle under one metre cube) of fresh air per minute for each pupil up to the maximum number allowed for the room in question; while the heating plant should be adequate to raise the temperature to 70 Fahrenheit in zero weather" (Hamlin, 1910, p. 9).

Classrooms during this period, especially larger ones in urban areas, were growing increasingly reliant on artificial ventilation, and Hamlin notes that in his perspective, this trend is playing out well, saying, "[t]he importance of adequate artificial ventilation cannot be exaggerated, and modern schoolhouses are, as a rule, much better equipped in this respect than was formerly thought necessary" (ibid). Yet, despite the growing importance of artificial ventilation, Hamlin at least was clear about his priorities in classroom air quality, saying in the conclusion of his guidance on ventilation that "however perfect the heating and ventilating plant, and however faultless its operation, let it be clearly understood and always remembered that no artificial heating and ventilation can ever take the place of fresh outdoor air and sunshine" (Hamlin, 1910, p. 9).

2.1.2 Lighting

Daylighting was a fundamentally important aspect of earlier school buildings, due to the lack of electric lighting available for illumination. School buildings were carefully planned and situated to take advantage of the best natural lighting conditions, and these were carefully documented and thoroughly understood by architects at that time. Indeed, they seem to have even more specific notions of adequate daylighting than we do today. A number of scholars point out that "Light should come over the left shoulder of each pupil" (Hamlin, 1910, p. 8). Apparently this view was based on the assumption that students should write with their right hand, and thus light coming over their right shoulder would be blocked by their arm. Figure 4 shows a diagrammatic explanation of how classroom spaces should be lit, noting the importance of avoiding dark spots from windows that do not extend all the way to the ceiling, and windows with large wall sections between them, practices that were believed to compromise visual comfort.

Daylighting standards at this time were often rather prescriptive, calling for specific window areas and window-to-floor area ratios. Since classroom spaces were highly standardized, this seemed to work for a great number of school buildings, and indeed, one can still see these commonalities in existing school buildings from this era today. In one particularly detailed instruction, one author outlines the proper daylighting technique:

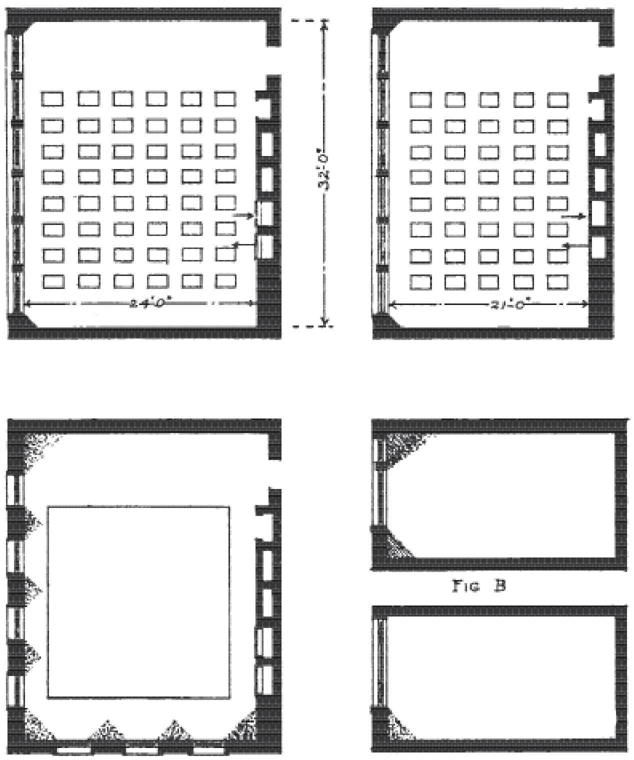


FIG A FIG C

LIGHTING AND SEATING OF SCHOOL ROOMS.

The upper drawings show ideal designs for school rooms, one to seat 48 and the other 40 pupils. Dimensions given, also the arrangement of windows, heat and vent flues, door, etc., correspond with the best present day practice. Some authorities insist upon two exits, and such should be the case in non-fireproof buildings.

Fig. A, illustrates imperfect lighting with dark spaces between windows and in corners.

Fig. B, is a vertical section through the school room, illustrating the light shut out near ceiling by transom bars and fancy top windows.

Fig. C, is a similar section showing correct location of windows with reference to floor and ceiling.

27

Figure 4. Diagram showing ideal and "imperfect" lighting configuration for classrooms, from Mills 1910

> The total window area should equal from 40 to 50 percent of the total wall area of the long side of the room, and in general, one-quarter the floor area of the classroom. The windows should extend up to within 6 inches of the ceiling; the window stools should be from 3 to 3 ½ feet from the floor. Light from below that level is useless; it is the height of the top of the window that determines its lighting efficiency. The sill should, however, not be higher than 3 ½ feet from the floor, as it is desirable that the pupils should be able to rest their eyes at times by looking out at more or less distant objects, which is impossible for many with a sill 4 ½ or even 4 feet high (Hamlin, 1910, p. 8).

It is interesting to note the mention here of the importance of view, referenced in a casual but logical way, suggesting that pupils should be able to "rest their eyes at times". This simple way of explaining the need for views would largely disappear in the century to follow, as school classroom design became increasingly engineered and economized.

Early standards for electrical lighting in classrooms were also published during this period. During this time, artificial lighting was entirely provided in the form of incandescent light, and thus was only possible in fairly small amounts, due to cost, logistics, and heat output issues. In 1918, the Illumination Engineering Society published the *Code of Lighting School Buildings,* which called for *3 footcandles minimum* of artificial light in classrooms, noting that "ordinary practice" was more in the range of 3.5 – 6.0 footcandles (Osterhaus, 1993). This would soon change, however, as fluorescent lights were introduced in the late 1930s, and lighting standards would grow increasingly influenced not only by need, but by technical potential, and therefore by lighting manufacturers seeking larger application for their products (ibid).

3 | The Progressive Era (1930-1945)

Despite the Depression, there was actually a fair amount of school building accomplished in the 1930s due to the funding of the Public Works Administration, which provided financing for 70 percent of new school construction for local communities (Weisser, 2006). Throughout the 1930s and 1940s, most schools were still built using the metrics and design principles of earlier decades, although there was increasing interest in newer models for education. As these attitudes were changing, a new generation of school reformers was emerging, through the leadership of such figures as Maria Montessori in Italy and John Dewey in the U.S. These scholars supported the notion of child-centered learning, and developed educational theories that form the basis for much current educational thought to this day (Hille, 2011). Alongside these educational visionaries was a generation of architects that came to the support of these new schools, and the 1920s and 1930s saw an alternative wave of "progressive" schools built to house these new programs. Many of these notable school buildings were built by the innovative architects of the day, including Eliel Saarinen and his Cranbrook Boys' School (completed in 1925), Alvar Aalto's Tehtaanmaki School (1937), and Richard Neutra's many modern school buildings built throughout the 1930s (Hille, 2011). These schools came to be known as the "open air school" movement, due to the emphasis they placed on air, light, outdoor learning and easy circulation through the school buildings. Interestingly, Hille calls these schools "functionalist", because they emphasized the importance of fresh air, outdoor activity and physical health as fundamentals of mental well-being. However, they look rather less functional than many of the school buildings of that day, in which students were kept in neat rows of desks and lectured to by teachers for much of the school day. One fine example of this architectural style can be seen in Walter Gropius and Maxwell Fry's Impington Village College, a combination high school and community adult learning center built in 1936 (see Figure 5). It is striking to note the relative timelessness of the floor-to-ceiling windows and operable façade depicted in the photograph (which was taken recently, as the school is still in use); this type of design could easily be employed in classroom designs today, which emphasize large expanses of window and connection to the outdoors.

The open air school trend was picked up in more mainstream circles of architectural thought in the 1930s, with scholars noting the importance of re-thinking school building design. In his 1935 article on "Needed Research in the Field of School Buildings and Equipment", Holy notes, "...in the past, and to a great extent at present, the process of education has been largely a sitting-at-a-desk one with the major emphasis on textbook study.... The broadening curriculum, the more active methods of learning, and emphasis upon doing and working with things rather than merely studying books- all have focused attention upon the importance of the physical environment and the supply of materials necessary for this changed type of work" (p. 406).

Figure 5. The Impington Village College, by Gropius and Fry, 1936, photo courtesy of Hille, 2011

It was also during this time in the 1930s that growing attention was focusing on the need to standardize school facility management and construction. This decade saw the creation of the National Council on Schoolhouse Construction which would become today's Council of Educational Facility Planners International, a trade group for those who design and maintain school buildings. The 1930s also produced interest in the psychological effects of school buildings, as open plan school designs were focusing more on the importance of child-centered design. Essentially, the movement spurred the need for research, as was mentioned by Holy, in the first of a set of regularly published reports on *The Needed Research in the Field of School Buildings,* saying, "[p]erhaps most people would agree that there is a relationship between the quality of the school plant and the character of the educational program, but little evidence of this relationship is available" (Holy, 1935, p. 408).

There were fewer significant strides made in the development of indoor environmental quality (IEQ) standards during this era, roughly due to the depression and the difficulties the building industry was going through at that time due to economic problems and then the start of World War II. However, significant changes were about to hit, as the nation (and indeed, the world) emerged from the war in 1945.

4 | Post-war boom (1945-1960)

In October of 1949, *Architectural Forum* magazine published a special issue dedicated to school design that included articles about acoustics, lighting, heating and ventilating, and many more aspects of school design. Many architectural magazines published similar issues covering the explosion of school construction, commenting similarly on the exciting and daunting task ahead. In the introduction to the Architectural Forum issue, the editor notes, “Children, not tanks, planes or bombs- were the greatest output of the U.S. during World War II. These war babies, seven million of them, began hitting the first grade last year, have taxed every school facility, are

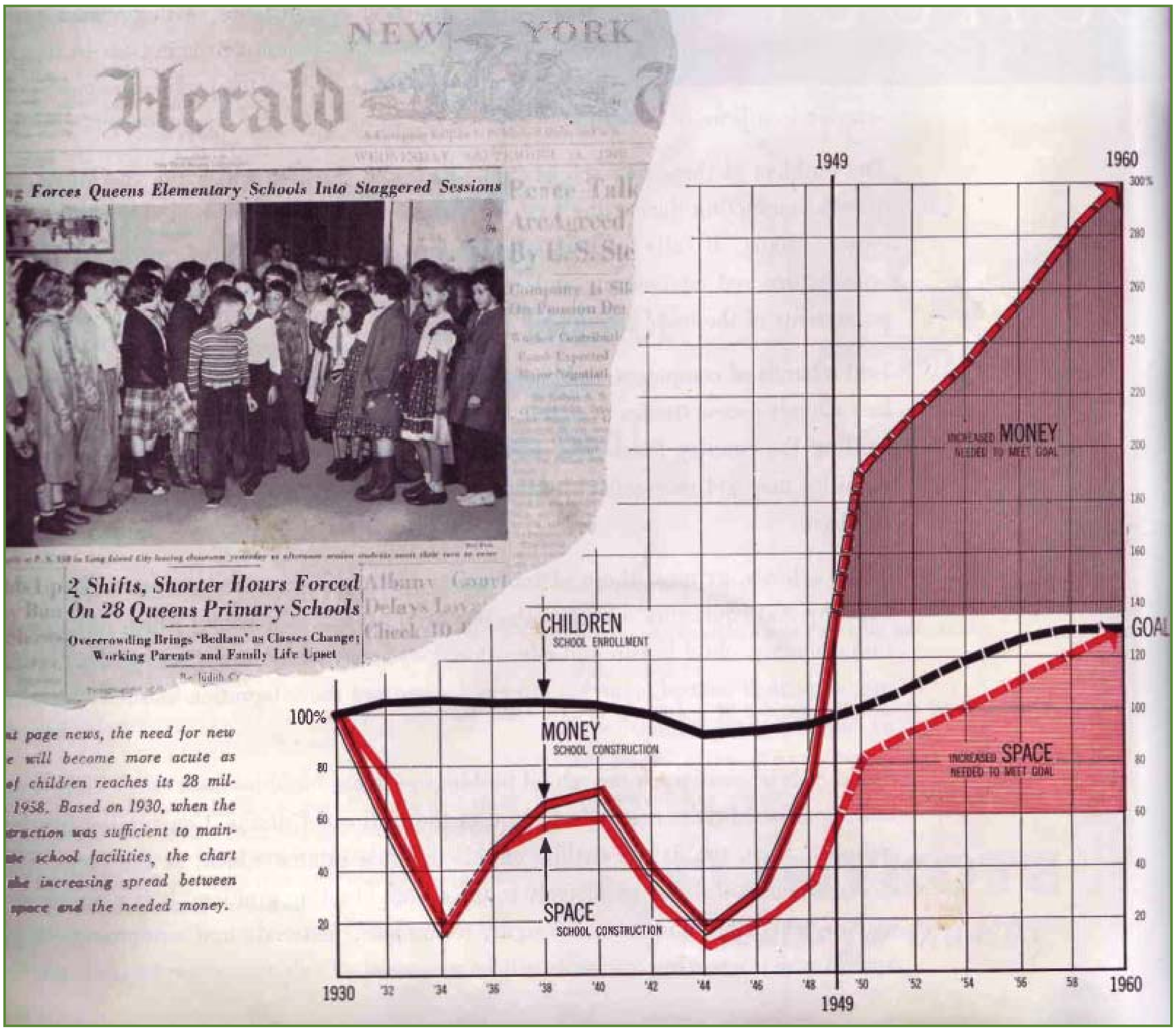


Figure 6. From Architectural Forum’s special issue on schools in 1949, a graph showing predicted needs in school construction to meet increasing enrollment demands

giving school men, parents and taxpayers alike a major problem concerned with the future of America." "Ten billion dollars, so the experts believe, must be spent for new school construction during the next 11 years.... Further complicating the problem is the fact that school building standards have risen steeply during the past decade, outmoding the 1940 classroom. This need bespeaks the spending of four times as much money as went into school buildings during the last 11 years" (Luce, 1949, p. 81). Figure 6 shows Luce's estimate, noting the current deficit in school space.

In fact, $20 billion was spent on new educational facilities from the end of World War II through 1964 (National Council on Schoolhouse Construction, 1964). The student population rose by 2.3 million students in just the decade between 1958 and 1968. As Tanner and Lackney note, "this period was the beginning of a new age of innovation in educational architecture, although many school boards missed the opportunity to create better school facilities as they struggled to cope with ever-increasing enrollments" (Tanner & Lackney, 2005, p. 12). They go on to describe that, "like the building boom earlier in the century, the 1950s saw a proliferation of standardized plans and facades that has characterized educational architecture of that period".

However, school districts did take the opportunity to follow some new trends in school design. New school buildings of that era "were no longer classical or colonial, Georgian or Gothic in architectural style but were truly modern in that they were one-story, flat-roofed structures enclosed in either glass and metal window wall systems or brick and concrete wall systems" (Tanner & Lackney, 2005, p. 12). Tanner and Lackney also note that this was the first time that air-conditioning was installed in school buildings. Figure 7 shows an example of this common school facade style and configuration, in a photograph taken in recent years.

Modern architects were mostly confident in the logic and efficiency of school construction during this era; its considerably different appearance from past styles may have contributed to this confidence. Hille comments on this attitude, saying,

Figure 7. A typical school facade built in the 1950s, courtesy of Dudek, 2000.

> In practical terms, the modern school as it developed in the United States at this time, was determined to have a number of practical and functional advantages over the traditional two- or three-story brick schoolhouse. To begin with, its lightweight construction, which utilized new building technologies, was less expensive and easier to build, and although its life expectancy was shorter, it was argued that schools needed to be rebuilt periodically anyway (Hille, 2011, p. 91).

Hille also notes that the standard façade was comprised of "continuous full-height ribbon windows [that] provided natural light along the outer walls, with doorway access from individual classrooms directly to the outside."

It was during this building boom that the concept of the finger-plan school gained popularity. An early example of this style can be seen in the Crow Island School, which opened in 1940, just before the boom began. Designed by Perkins & Will, the school would become, as Tanner and Lackney note, "the school building that more than any other defined modern educational architecture in the United States" ((Tanner & Lackney, 2005, p. 12). Figure 8 shows the plan of the school, where corridors spread out across the plan, forming fingers off of which each classroom extends. This configuration allowed each classroom to have access to maximum amounts of fresh air and light, and allowed for many classrooms to have direct access outside through exterior doors.

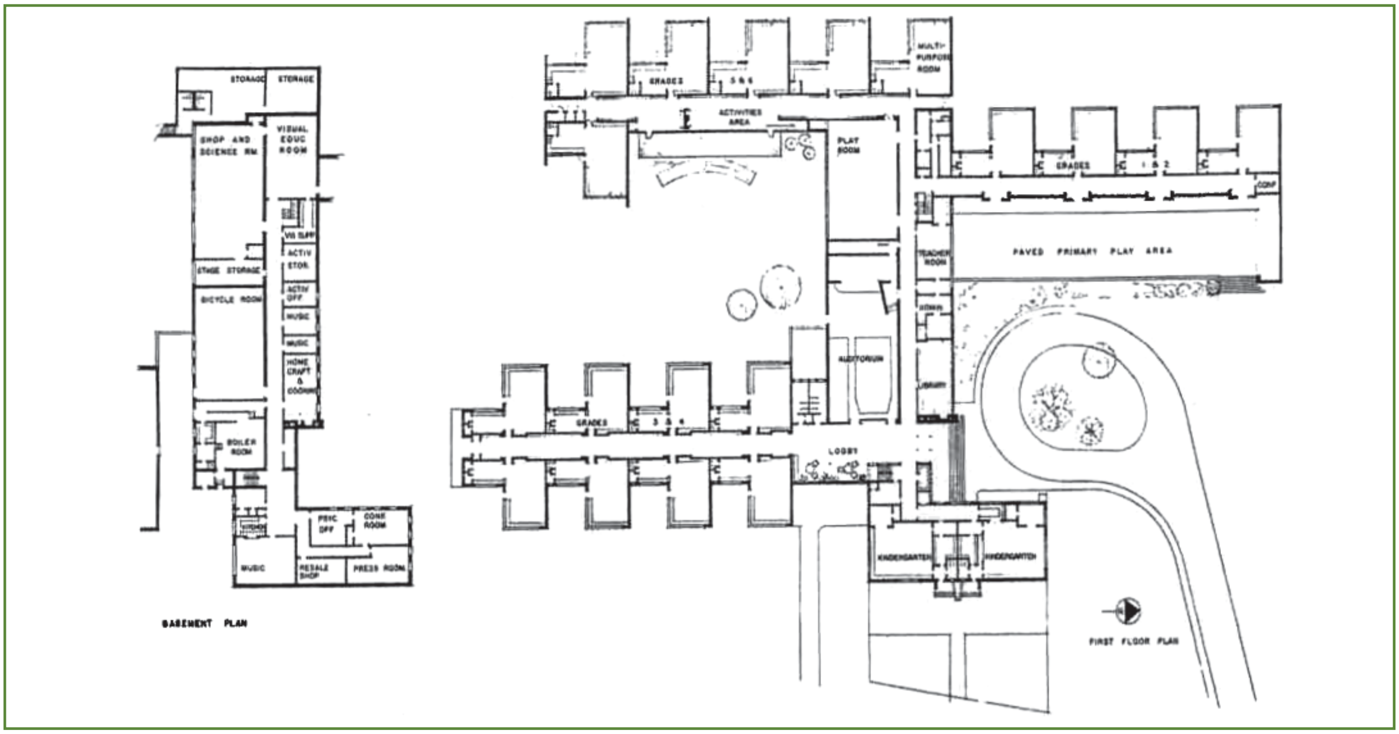


Figure 8. Crow Island School, Perkins & Will Architects, courtesy of Tanner and Lackney, 2005.

In one guidebook published at the time, authors noted another major reason for building schools only one story high, saying, "[m]ulti-story buildings are more difficult to evacuate than single-story buildings" (National Council on Schoolhouse Construction, 1964, p. 96).

4.1 Evaluation and standards

4.1.1 Ventilation, Heating and Air Quality

In a report written by the chief of the School Housing Section of the U.S. Office of Education (later known as the Department of Education), Ray Hamon detailed the needs for research in his field in a 1948 article, noting that often the research did not match current practice, saying, "[t]here has probably been more research on heating and ventilating than on any other feature of the school plant. Although there has been rather general agreement on desirable conditions, many codes are still based on false principles" (Hamon, 1948). In a similar article in 1951, Gray notes some specific areas of research that are still in question today in regards to heating and ventilation:

> In the field of heating and ventilation the following are some of the unanswered questions: (a) Is window-gravity-ventilation feasible and satisfactory in all climates and seasons? (b) If mechanical systems of heating and ventilating are used, what are the optimum volumes of air per pupil, numbers of air changes, and proportions of fresh and recirculated air? (c) What are the optimum temperature and humidity conditions for health and alertness in the different school activities(Gray, 1951)?

At this point in the evolution of ventilation standards for classrooms, required cubic feet per minute (cfm) per person had been lowered to 10 (from 30 cfm in the 1920s). This was a result of research conducted for the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) then known as the American Society of Heating and Ventilating Engineers (ASHVE), by Yaglou and his colleagues in the late 1930s which measured olfactory sensation in rooms, where they determined that air was not perceptibly bad until ventilation rates were lower than 10 cfm (Janssen, 1999). This research was the support for codes using the 10 cfm threshold starting in the 1930s and continuing through the first version of ASHRAE 62 - *Standard for Natural and Mechanical Ventilation* in 1973.

In the Architectural Forum issue, thermal comfort is introduced as a particularly difficult area of school design, with the author noting, “there are few types of work in which the static analysis that is the basis of most heating design comes into such open and obvious conflict with the everyday realities as in the school classroom” (Luce, 1949, p. 144). He goes on to remind the reader,

> This is so in the first place because the use of such rooms, and consequently their heating, is on an intermittent rather than a constant or nearly constant basis. Schoolrooms are normally used only during the daytime, and during the middle daylight hours at that.... Secondly, schoolrooms are in use during the time of day when solar heat gain is at a peak.... Since almost all classrooms today have a great deal of class- from 20 per cent of the floor area upwards- the solar heat gain is tremendous.... Finally, classroom heating is complicated by density of occupancy (ibid).

This heat flux is carefully depicted in a lovely graphic reproduced in Figure 9. The author then goes on to caution the reader about the large expanse of windows, noting that this can cause significant thermal discomfort in occupants, especially those sitting near a window. In another charming illustration that can be seen in Figure 10, the author explains that the cold surfaces of windows can be offset by heating panels placed below the windows and on the ceiling above windows, to help combat this problem.

In general, as can be seen from the writings of this period, thermal comfort was becoming an increasingly technical and complex field, and expertise was growing ever more specific as mechanical engineers took on greater responsibilities in providing narrow temperature bands and specific humidity levels for classrooms. This

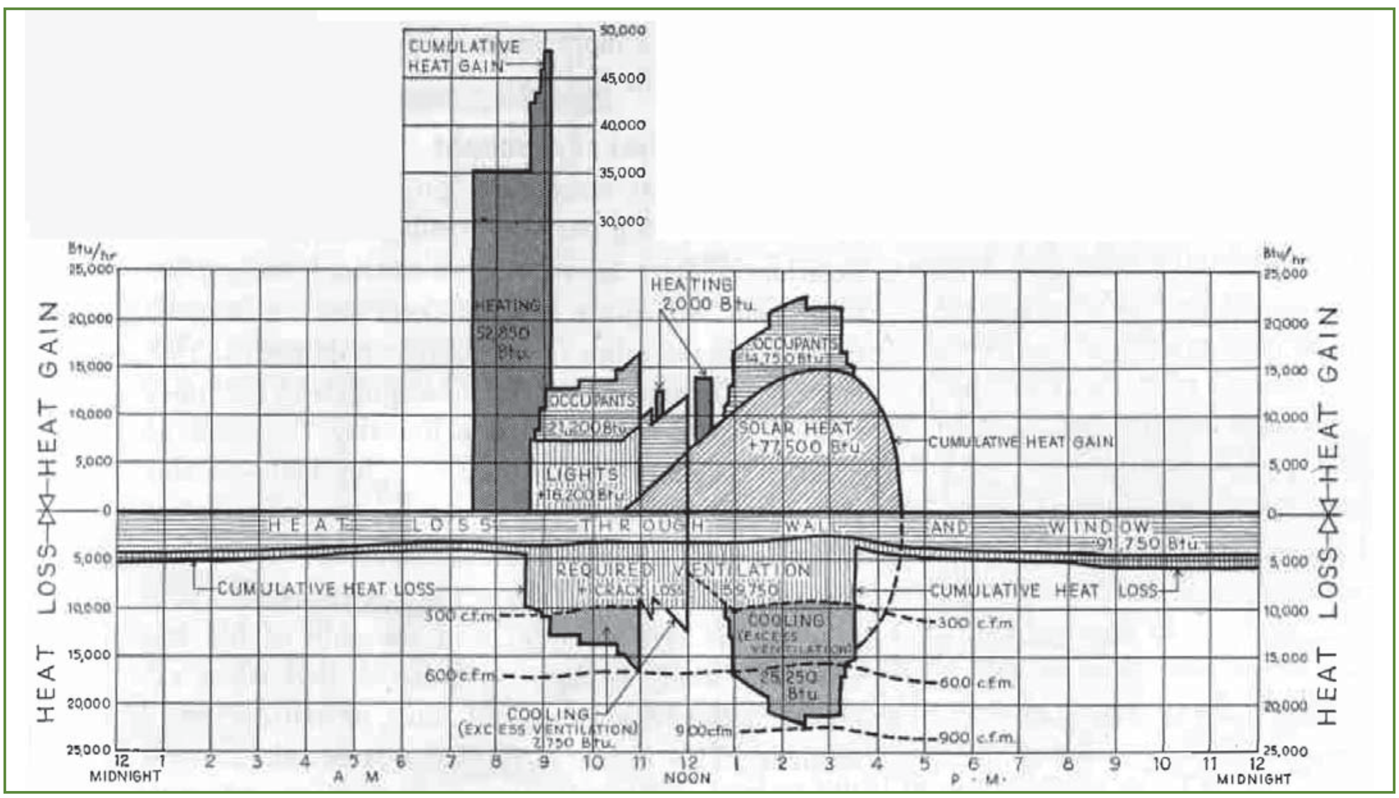


Figure 9. A conceptual graph of the heat flux in a typical classroom, from Architectural Forum, 1949.

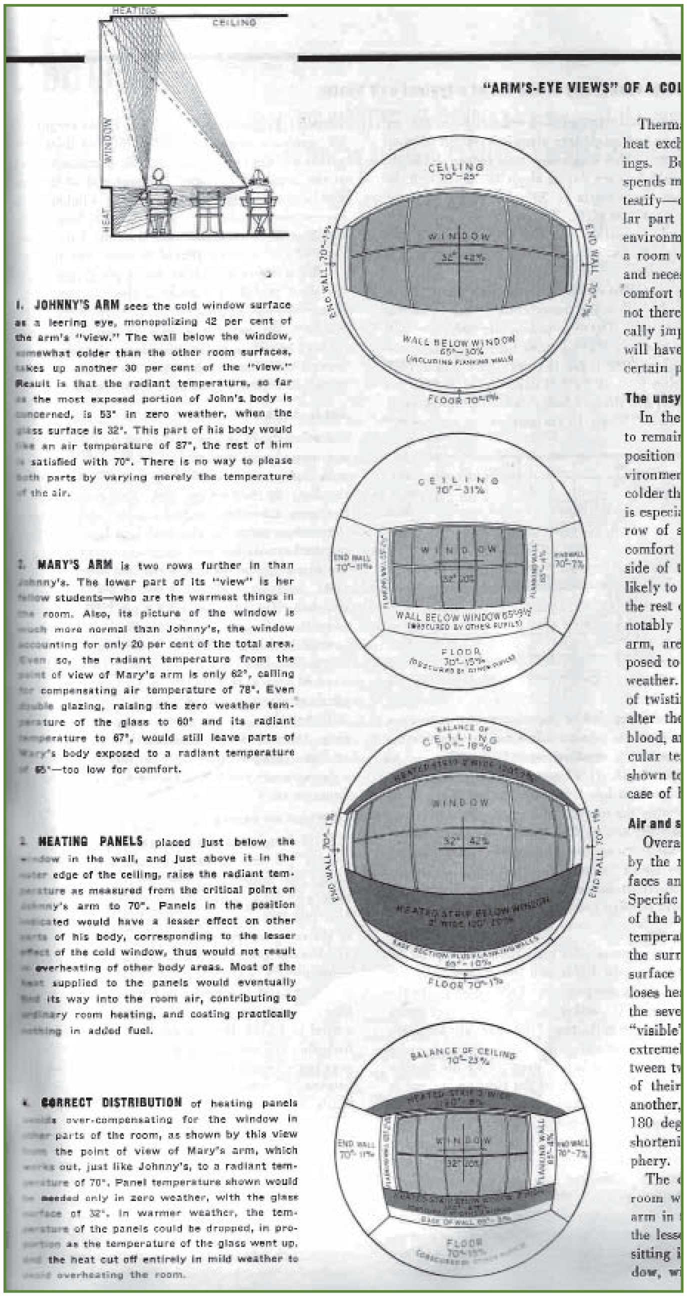


Figure 10. From Architectural Forum, 1949, an explanation of the dynamics of thermal asymmetry and radiant surfaces.

was another instance where the changes in standards were more related to technological advances, rather than our understanding of human needs and comfort. Whether these conditions were achieved in actual classroom settings is not well understood, as few field studies are available for that time period.

4.1.2 Lighting

During the 1940s and 1950s, the emergence of inexpensive fluorescent lighting was creating the opportunity that schools had not had previously, to artificially light classrooms rather than rely on natural sources of light through windows. It was a transitional time when lighting standards for classrooms were shifting, and perspectives were changing rapidly on how classrooms should be lit. Towards the end of this period, in 1959, researchers from the Illuminating Engineering Society used a testing procedure called the Visual Task Evaluator to determine a host of new light level standards, including an increase from the previously established 30 footcandles for classrooms to 70 footcandles (Building Research Institute, 1959). Incidentally, lighting standards have remained largely the same since this transition in 1959. However, school designs during the 1940s and 1950s tended to provide ample natural light along with the newly added artificial light. Although little evidence exists to know whether teachers at that time preferred natural or artificial light, there was clearly growing interest in ensuring a quality visual environment through the mixture of these two modes. Hamon outlined his perception of this area of research in the following way:

> There has been some research and a great deal of pseudo-research in the field of school lighting. The field is still very confused by conflicting opinions, commercial claims, and half-truths. The shift of emphasis from foot-candles to good seeing conditions has made much of the earlier lighting research obsolete. School lighting involves three factors which must be studied in their relationship to each and their effects on balanced brightness within the total visual environment. These factors are fenestration, surface finishes, and artificial illumination. Following are some of the major subjects on which fundamental research should be undertaken: ... (b) amount and placement of areas designed as natural light sources under different climatic conditions; ... (d) shading and shielding devices for reducing glare from natural light sources...(Hamon, 1948).

Hamon draws attention to a number of notable issues in this passage. First is the note regarding the shift from the measurement of daylight purely using foot-candles or illuminance levels to a more comprehensive consid-

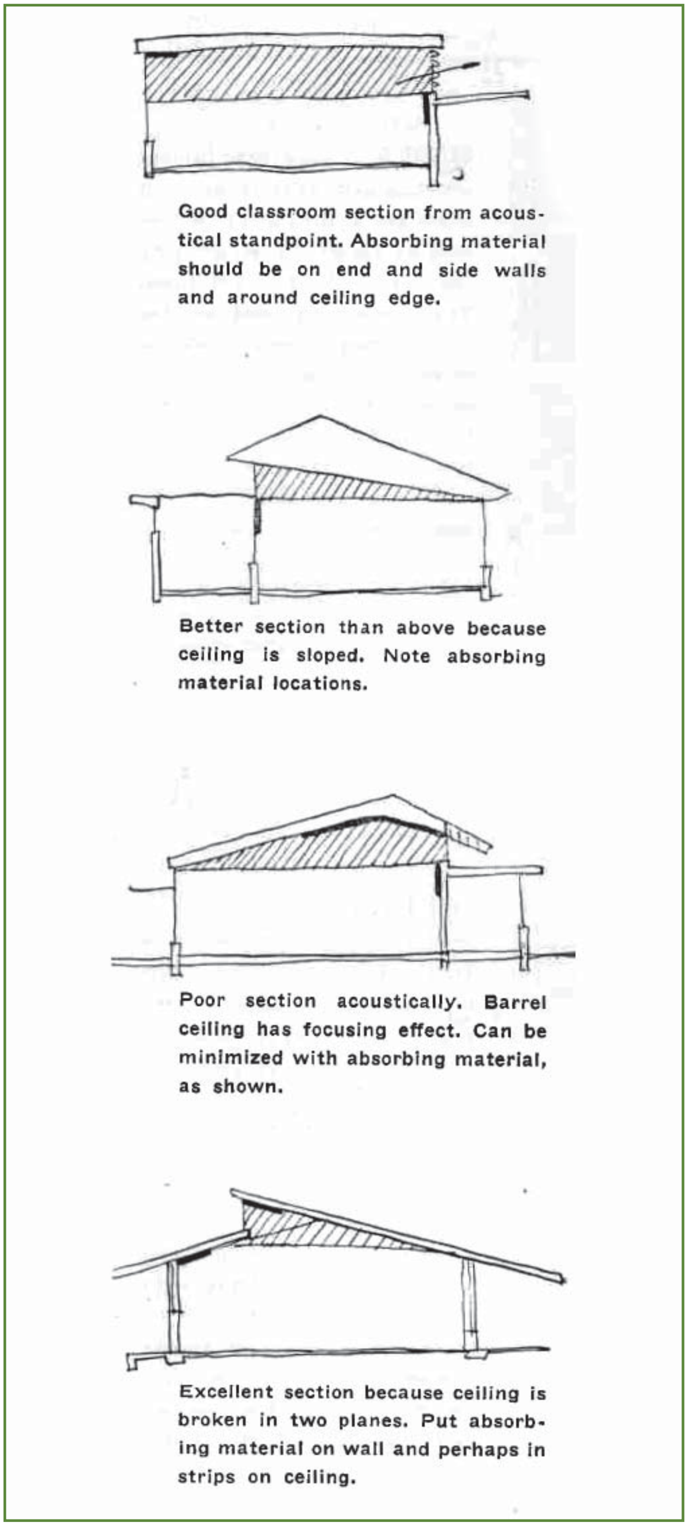


Figure 11. From Architectural Forum, 1949, p. 152, showing how the classroom section can be configured for acoustic quality

eration of visual comfort, including glare and attention to surface finishes. This may have been a problem that was exacerbated by the opportunity for artificial lighting, which may have produced additional glare issues itself, or may have simply allowed designers to worry less about even natural light distribution, leading to less visually comfortable spaces. It may have also simply been a problem of the increasing amounts of fenestration that were going into schools during that time, inspired by the open air schools of the 1930s. Regardless of the reason, Hamon was right to point out this issue in school buildings; many schools built in the 1950s have natural light from one side only, to the effect of providing very uneven distribution in classrooms.

Another issue mentioned here is the need to shade windows for glare reduction, a concern that was largely absent in earlier writings on daylighting in classrooms. As artificial light became an option, teachers may have been more inclined to use the more evenly distributed light from overhead fixtures, but would not necessarily had the ability to screen out natural light. This was also the era when slide projectors emerged as a learning tool in classrooms, necessitating the periodic darkening of classrooms to show slides, which may have had an impact on the need for more control over natural light sources. Little evidence is available to ascertain whether curtains or shades would have been common fixtures in classrooms prior to 1950, but this passage seems to indicate that this was not common practice.

4.1.3 Acoustics

As school construction and the basic geometries of classrooms became more standardized throughout the 1950s and 1960s, architects began devoting more attention to designing classrooms for acoustic performance. In addition, as educational models were expanding to allow for other modes of learning, there was more of a need for acoustic control. This was explained by Hamon, in noting, “[s]ound control has become an important problem in schools, because of more informal school procedures and a greater use of non-sound-absorbent building materials. There are many acoustical materials available for many purposes. Research is needed to determine the amount of sound control necessary for various areas of the school building, and the types and amounts of materials required for satisfactory results in different areas (Hamon, 1948, p. 6)."

In the *Architectural Forum* issue on schools, acoustics received equal billing with ventilation and lighting as a key performance area to focus attention on when designing schools. Figure 11 shows a set of classroom sections and their related impacts on acoustics, showing how school designers were taking these issues into consideration in fundamental design decisions. The accompanying article discusses the need for attention to sound isolation, low background noise and other standard principals of good acoustical design. In introducing the topic, the authors note, "the field of architectural acoustics is concerned primarily with the provision of both satisfactory acoustic environment and good hearing conditions" (Luce, 1949, p. 152). They go on to explain these two concepts, the first of which deals with the exclusion of outdoor noise and noise transmission through interior walls, while the second addresses acoustics at the classroom level. In this latter area, the authors go on to point out many of the same acoustical variables we consider today, saying, "to provide good hearing conditions in any room requires the satisfaction of four basic requirements: 1) Sufficiently low level of background noise. 2) Adequate separation of successive sounds (reverberation control). 3) Proper distribution of sound within the space. 4) Sufficient loudness of sounds" (ibid). Again, it should be noted that although these standards were being published at this time, as the authors themselves note, this bears little resemblance to the actual constructed schools of that day, which were largely not addressing the concerns of the author. It would not be until later eras, as acoustical standards and guidelines for classrooms were published, that these practices would become somewhat more common.

5 | The "Impulsive" Period (1960-1980)

In their review on the history of Norwegian school construction trends, Hansen and Hanssen call the era between 1965 and 1980 the "impulsive" period, and however fair, many contemporary scholars have settled on that opinion of this era and its "Age of Aquarius" mentality.

However, another major influence on school buildings at this time was declining school enrollment, and schools were faced with the prospect of re-thinking and reconfiguring existing school space in the face of shifting populations. Not only were school populations shrinking, but this era also saw the fundamental shift to desegregated schools, which had a profound impact on equity issues in school facilities, especially in urban areas (Hille, 2011).

Tanner and Lackney note that social unrest during this period also spurred the development of experimental school buildings, along with a healthy dose of criticism about the state of education and educational facilities at that time. They note that "criticism was especially centered on urban cities where large neighborhood comprehensive schools were not providing adequate education in meeting the needs of minority, disadvantaged, and low-income youths... and also focused on the perception that public schools were stifling to creativity and destroying children's natural love of learning and self-expression" (Tanner & Lackney, 2005, p. 17).

On the educational side, researchers were starting to recognize the connection between school facilities and student learning, as was noted by one researcher in her ground-breaking review of research, saying, "In the last decade... increasing numbers of educators have begun to believe that other dimensions of the physical environment might have an impact on students' behavior and attitudes" (Wienstein, 1979, p. 577). She notes that this may be due to the emergence of the field of environmental psychology, but also notes that it comes from the growth of two "controversial educational movements, *open education classrooms* and *open space schools,* both of which imply new approaches to using classroom space" (ibid).

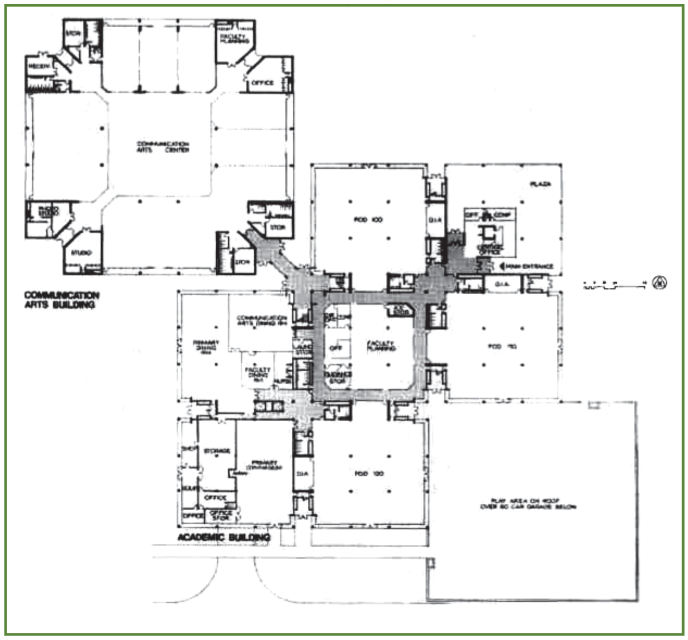


Figure 12. From Tanner and Lackney, 2006, The floor plan of the "open plan" Disney School, designed by Perkins & Will, Architects

A major player in the field of theory and practice of school design in the 1970s was the Educational Facilities Laboratory (EFL), a research organization funded by the Ford Foundation from 1958 through 1977 (see Marks, 2009 for a history of this organization). They were well-known for their forward-thinking research into school facilities, and specifically their role in promoting the open plan (or open space) school (Educational Facilities Laboratories Inc., 1970; Marks, 2009). An example of the open plan school layout can be seen in Figure 12, in the floor plan for the Disney School in Chicago, designed by Perkins & Will in 1960. Large "pod" areas served as the major classroom spaces, with little definition of space within them. Weinstein and others note that these open plan schools would often not have windows either (whether this was related to the open plan scheme or not is hard to tell- it may have simply been related to energy conservation).

These open plan schools were not introduced blindly, but were accompanied by some thorough research. Weinstein reports on one open-plan school that had already received retrofit treatment by 1979, and the effects of the retrofit had been measured, although the study itself had not been published (and could not be found today). Researchers found that the modifications of variable-height, sound-absorbent partitions between classrooms significantly reduced classroom interruptions and increased substantive, content questioning (Wienstein, 1979, p. 582). However, she also recognizes that much of the research on open-plan schools was conflicting, and as such, she cautioned the reader, "[a]t the present time, it is still necessary to suspend judgment about the success or failure of the open space school to enhance the educational experience of children" (ibid, p. 598).

Another project that brought attention to the EFL was the School Construction Systems Development Program (SCSD), which was a major effort to bring prefabricated construction techniques to school construction. The program was largely a joint effort between researchers at Stanford University and the University of California at Berkeley, and was seen by many to be a major contribution, with one retrospective calling it, "clearly the major experimental building program of the sixties. The methods, procedures, and hardware systems developed as a result have had a profound influence on American design and construction" (Rand and Arnold, 1979, as quoted in Marks 2009). SCSD "sought to apply industrial techniques of standardization and systems analysis in an attempt to develop a new and more economical building technology (Boice, 1968)." It involved, officially, 12 secondary schools and one elementary school in California, but 1300 schools in California contain a subsystem developed through the SCSD program (Griffin, 1971). Most of the systems described seem to be related to structure and envelope, but it is unclear whether any of these systems are still in use today.

5.1 Energy consumption trends

Following the energy crisis of 1973, energy codes and regulations began to radically change the priorities of school facility professions, towards the need to reduce energy consumption above all other priorities. It was during this time that school designs and renovations capitulated to the relative simplicity of relying on mechanical systems to provide requisite lighting and thermal conditions. Since it was also a time when few new schools were being built, the focus was on the energy-efficient renovation of existing schools, especially those from the early parts of the century. While this had its benefits, there were many unfortunate decisions made at this time, in particular in regards to windows. Schools like the H.B. Plant High School in Tampa, Florida, built in 1927, had many of their large windows closed off to save heating and cooling energy, since they were no longer necessary to provide light to classrooms. As Hille notes, this common practice "severely impacted the quality of natural light, natural ventilation, and in general, the sense of indoor-outdoor connectivity- all of which were mainstay characteristics of the modern school" (Hille, 2011, p. 163). These decisions are largely being reversed today, and the Plant High School and many others are seeing their historic windows restored (at a great cost, of course- the total renovation cost for the Plant school was $12 million) (Kennedy, 2003).

The energy crisis also served as the impetus for the largest federal energy-related building retrofit program in history, the Institutional Conservation Program, also known as the Schools and Hospitals program, which was initiated in 1977. This program built significant awareness at state and local levels about the importance of energy conservation in school buildings. This federally supported effort brought the issue of wasted energy to the nation's attention, and spurred significant research into other means of saving energy in schools.

5.2 Evaluation and standards

5.2.1 Ventilation, Heating and Air Quality

The 1960s and 1970s saw many changes in standard practice and common wisdom in classroom thermal comfort and air quality. Of course, at the time, scholars and authors of relevant texts showed no signs of doubt as to the validity of current knowledge on these matters. For example, one architect from the period writes, "[u]ntil recently, schools in many areas have been over-ventilated. The old rule of thumb specifying that every classroom provide 30 cubic feet of fresh air per minute for each student is now being replaced by fresh air require-

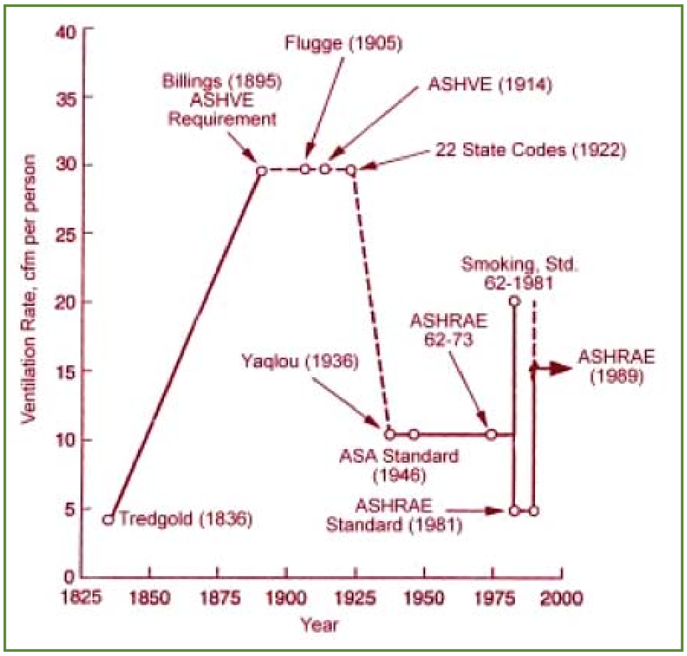


Figure 13. From Janssen, 1999, a graph depicting the changes in minimum ventilation rate in ASHRAE history

ments that are more reasonable.... It is fairly well agreed among school planners and designers that a ventilation system providing between 10 and 15 cubic feet of fresh air per student per minute is adequate for the dilution and removal of obnoxious substances from the air in classrooms"(Castaldi, 1969, p. 214). However, as soon as the energy crisis hit, there was no longer general agreement that 10 cfm per student was the adequate amount. In fact, the next major release of ASHRAE 62 in 1981 lowered the 10 cfm minimum to 5 cfm for all spaces (not just classrooms), largely due to the pressures of energy conservation (Janssen, 1999). Shockingly, there was also a standard for classrooms where smoking was allowed, which was 25 cfm/person. This minimum persisted for only 8 years, and was raised back to 15 cfm/person minimum in ASHRAE 62-1989 (see Figure 13).

Hansen and Hanssen note that ventilation systems at this time were also influenced by open plan classrooms, which required very different ventilation configurations. They also note that during this time, when energy conservation was a major concern especially for their country Norway, 100% recirculated air was common (Hansen & Hanssen, 2002). Although they do not note whether this was true in the U.S., it stands to reason that this would have been the case in some states, especially those in colder climates.

Other thermal comfort standards were getting increasingly stringent during the 1960s, as mechanical equipment allowed for ever smaller bands of acceptable comfort. According to guidance documents released by the National Council for School Construction (NCSC), "sudden fluctuations of heating or cooling in room air temperature due to equipment going on and off should not be more than + or – 1 F, and preferably less (NCSC, 1964, p. 116)." It was also during this time that there is first mention of the desirability of reducing window area, now that mechanical systems were covering the tasks once given to windows. Again, the NCSC notes, "[t]he reduction of the use of large areas of glass for natural sky light improves system performance in every respect (ibid)." It should be noted that these declarations came before the energy crisis hit in 1973, indicating that it was not merely the desire for energy conservation that contributed to the transition away from naturally ventilated and lit classrooms, but also a proactive decision to use mechanical equipment instead, because of its perceived greater reliability and ease of design.

Castaldi also notes the growing installation of air-conditioning in schools during this era, noting that "[g]eneral air-conditioning is receiving much attention in the planning of educational facilities. The prospect that school and college buildings may soon be used year round strongly accentuates the need for cooling as well as heating"(Castaldi, 1969, p. 216). Although there was no substantial reason why year-round schooling was being considered at this time, it appears as if many school districts took the precaution just in case, as there was no documented increase in the use of school buildings over the summer in the decades that followed.

5.2.2 Lighting

Heating and ventilation were not the only aspects of school design affected by the energy conservation movement in the 1970s. Some may argue that it was most acutely felt in the field of lighting. Again, as the 1960s were ending, there is evidence that the industry was becoming more comfortable with artificial lighting, as is represented by Castaldi in 1969, saying, "Recently, the emphasis has shifted from natural to artificial illumination, which no longer fixes the width of any space in which adequate lighting is desired" (Castaldi, 1969, p. 194). The NCSC also supported this trend, noting that "the sky, direct sunlight on windows, and the bright wall areas of adjacent buildings are the most common sources of excessive brightnesses, and upset the balance of brightness recommended in this Guide"(NCSC, 1969, pg. 131).

This greater architectural freedom was further fueled by the energy crisis, and led to theories that questioned whether windowless classrooms might be an option. As Weinstein reviews, research conducted in the early 1970s showed that windowless classrooms had no discernable negative impacts on student learning, although teachers and students did complain about the conditions being unpleasant (Collins, 1975; Wienstein, 1979). However, complaints of occupants were not enough reason for architects of the time to avoid this strategy, and it gained popularity throughout the 1970s. Interestingly, Weinstein, an educational scholar, called windowless classrooms an "architectural innovation". Although some contemporary scholars and architects have conjectured that windowless classrooms were a product of educational theory, most evidence from that era supports the notion that it was an architectural choice based on the desire for more control over indoor environmental factors. She does, however, recognize other factors that may have contributed to this trend, noting "freedom from excessive heat, glare and distraction, increased space for bulletin boards and storage, decrease in vandalism, and opportunity for more flexible room arrangements" (ibid).

During this era, McGuffey (1982) also provided an overview of the research done in the field to date, noting that no significant difference in student performance had been documented in windowless classrooms. Similarly, he reviewed research that looked at underground schools, which were a proposed solution by the Department of Defense to use as fallout shelters. Again, no impact on student performance, anxiety levels, behavior or mood was noted. These historic findings are striking, in comparison to earlier writings insisting on the inherent value of the outdoors, and more current research that has found a distinct decrease in student health and well-being in windowless classrooms. Since all evidence shows that these were well-conducted studies, it should serve as a reminder for the importance of replicating and retesting research findings, especially in such decisions as windowless classrooms, where the consequences are long-lasting and difficult to alter.

One final area of thinking in regards to both heating and lighting was that of shade control. In a particularly definitive tone, NCSC thought it appropriate to declare in their guideline that "[t]eacher control of window shielding devices has not proved efficient. Even though teacher control may improve with proper supervision, it seems desirable to provide, insofar as possible, shielding devices that do not need to be manually operated" (NCSC, 1969, pg. 131). This early mention of the architectural desire to remove control from occupants would only be exaggerated in years to come, as school buildings became increasingly controlled and dependent on mechanical systems.

5.2.3 Acoustics

Acoustical standards and research gained popularity during the 1960s and 1970s, especially as the industry sought feedback on the effects of open plan schools. However, from the perspective of the authors of the NCSC guide, the "hit-and-miss type of sonic engineering" which they note "has characterized most school buildings" was common at that time (NCSC, 1964, p. 104). They continue, "[t]he application of some kind of acoustical material on the ceiling of classrooms and the specification of a 45-decibel sound reduction factor for partitions has unfortunately represented the general approach to the sonic refinement of school spaces."

In this NCSC guide, the authors also note a "major field study" that was conducted at that time, which showed that acoustic satisfaction in open plan classrooms was roughly on par with other classrooms, indicating, "that many of the ideas developed over the years concerning sound and sound control are open to challenge and reexamination (National Council on Schoolhouse Construction, 1964, p. 107).

Other research was beginning to emerge during that time which began to address the more quantitative limits of acoustical conditions and their impacts on student learning (Wienstein, 1979).

6 | Declines of the 1980s and the New Movements of the 1990s and 2000s

The 1980s were a time of decline and reflection for schools in America, as districts saw enrollments go down, investment in school facilities drop, and many busyed themselves with smaller renovation projects to keep aging facilities up to basic standards of functionality. As Hille notes, this was politically motivated as well, saying, "[i]n education, the conservative social and political mood of the 1980s resulted in a basic reconsideration of the educational experimentation of the 1960s and 1970s, and a renewed emphasis on basic academic subjects like math, science, and the humanities, preferably taught in more traditional educational venues" (Hille, 2011, p. 203). He goes on, "[a]ging facilities from the 1940s and 1950s were now in need of renovation and replacement" but as enrollments were declining, little investment was available, and the "pace of new school construction slowed dramatically" (ibid).

During the Reagan administration support for energy conservation programs also lagged, and many states ended up creating their own funding and programs to support energy conservation projects for their schools, but the national movement was significantly drained of its momentum.

In 1995, a comprehensive report was published by the General Accounting Office (GAO, now named the Government Accountability Office) on the sad state of school facilities in the U.S. (GAO, 1995). In this report, they estimated that $112 billion was needed just to bring the nation's school facilities up to "good overall condition". Much of this was for projects like asbestos removal, basic compliance with the Americans with Disabilities Act (ADA), and recently discovered problems with lead in the water supply. The report told many horror stories, like that of raw sewage leaking into a school's front lawn due to broken plumbing, and collapsing ceilings due to water damage in another. This report was very helpful for advocates looking for federal and state-level support for school facilities, but no direct federal policies or assistance resulted from the release of the report.

It was also during the 1980s and 1990s that the nation became aware of the problems of portable classrooms. Many of these classrooms were installed on school grounds throughout the 1980s due to difficulties in enrollment projections and other population changes. However, by the late 1990s, it was becoming increasingly obvious that these "temporary" classrooms were not so temporary after all. One report estimated that in the state of California alone, there were 75,000 portable classrooms, and that this number was increasing by 10,000 every year (Apte et al., 2002). Along with concerns about the general adequacy of these units, concerns were growing about the quality of the indoor environment in these spaces, leading to significant research projects in the late 1990s (Apte, et al., 2002; Chan, 2009). The studies found that portable classrooms had significantly higher levels of indoor air pollutants, while other related studies also reported that they often had unacceptably high levels of CO^2, an indicator of fresh air flow (Shendell et al., 2004).

The other major development in the field of school facilities in the 1990s and beyond was the emergence of the green building, or high-performance, building movement. Largely fueled by the launch of a new green building rating system, LEED (Leadership in Energy and Environmental Design) in 1998, this new movement grew significantly in the early 2000s, and today is largely acknowledged to be one of the most significant influences on school design and construction in recent years (Taylor, 2008; US Green Building Council, 2007). Along with the LEED standards, the Collaborative for High Performance Schools and its design criteria, based on LEED but written initially for school facilities in California, has also been an influence on the industry as it has provided a significant library of resources to help in the design, construction and maintenance of high-performance buildings (CHPS, 2006). These standards and organizations promote the responsible use of energy and natural resources while providing healthy indoor environmental conditions in buildings. While the movement has had its difficulties maintaining stringency in the face of growing interest in LEED certification, it has also had an enormously positive impact on the larger building industry. In particular, it has led the industry to address the sometimes conflicting goals of indoor environmental quality and energy conservation with renewed vigor and innovation.

6.1 Energy consumption trends

As energy conservation efforts continued steadily throughout the 1980s, some efforts were made to address the behavioral aspect of energy consumption in school buildings, by districts who thought of these efforts as the "low-hanging fruit" of no-cost energy conservation. One paper in *Energy Policy* in 1991 covered a small handful of programs in school districts across the country that emphasized behavioral adaptations, including ones in Berkeley and Oakland, California and Philadelphia, Pennsylvania (Wirtshafter & Denver, 1991). They noted critically that, "[t]raditional programmes, most particularly the Institutional Conservation Programme (ICP), have addressed the physical/technical needs of buildings without fully addressing the concerns of their human occupants" (ibid, p. 480). However, school districts continued to renovate aging buildings as necessary, often favoring newer mechanical and lighting systems above more fundamental retrofits (discussed in depth in section 8).

As noted above, moving into the 1990s and 2000s, school districts grew increasingly interested in high-performance building rating systems like LEED and CHPS, which also helped to spur interest for small renewable energy systems (mostly solar panels) in schools.

Ironically, however, the emphasis on green building in the past two decades has taken some of the momentum out of the energy efficiency movement, as federal, state and local agencies have turned their focus towards the more holistic sustainability metrics and away from simple energy performance. This would not be a problem necessarily except that research has shown that LEED certified buildings do not always perform particularly well in terms of energy consumption (Turner & Frankel, 2008).

6.2 Evaluation and standards

6.2.1 Ventilation, Heating and Air Quality

In recent years, the industry has largely reached a shared agreement about the basic needs of classrooms in terms of heating, ventilation and air quality, but some questions still remain. As Schneider notes, "students will perform mental tasks best in rooms kept at moderate humidity levels (forty to seventy percent) and moderate temperatures in the range of sixty-eight to seventy-four degrees Fahrenheit" (Schneider, 2002, p. 2). There is also growing appreciation of the need to keep CO2 levels below a certain level, although there is still some disagreement as to whether 1500 or 1000 ppm is the safe maximum level (ventilation researchers prefer 1000 ppm, while practitioners often cite 1500 ppm). This current debate is reviewed more in depth in a paper by Wyon & Wargocki (2007).

In regards to air quality, research in the 1990s and 2000s has found that many schools in the U.S. have significant problems with particulate matter and other air pollutants, leading some to speculate about the effect school air quality may have on growing asthma rates in children (Ribéron et al., 2002; Smedje & Norbäck, 2000; Zuraimi et al., 2007). However, scholars have noted that the research in this field is not conclusive, due to the paucity of well-controlled studies looking carefully at the effects of specific air quality factors (Daisey et al., 2003; Mendell & Heath, 2005).

Today, ASHRAE continues to support research investigating the connection between outdoor air supply and student performance, but ASHRAE Standard 62 (now 62.1) still uses the rate established by research from 1936, of 10 cfm per person as its minimum acceptable outdoor air ventilation rate (ASHRAE, 2010b; Janssen, 1999).

Another major development in the realm of thermal comfort and ventilation is the growing use of natural ventilation and mixed-mode systems and associated adaptive thermal comfort standards (Brager and de Dear, 1998). While these methods and standards are new to today's designers, they largely follow the inherent logic laid out by Hamlin over a century ago, when he declared that no artificial systems could ever take the place of fresh air and sunshine. The adaptive model of thermal comfort incorporates the goals of energy conservation and indoor environmental quality through work done by Brager and DeDear which shows that occupants in naturally ventilated environments (who necessarily have control over their window openings) have larger ranges of comfort in regards to temperature (ibid). This research has contributed to major changes in ASHRAE Standard

55 for Human Thermal Comfort (ASHRAE, 2010a). It has coincided with a design trend towards reconsidering the possibilities of ventilating classrooms naturally (or with mixed-mode systems), to which significant research is now being conducted (Kwok & Chun, 2003; Mumovic et al., 2009).

6.2.2 Lighting

Although illumination standards for classrooms have largely leveled off in recent years, there is still some disagreement about even the most basic question of how much illumination is necessary in classrooms. For example, the current ASHRAE Advanced Energy Design Guide, which is supported by IESNA (the former Illumination Engineering Society is now called the Illumination Society of North America), advocates for anywhere between 30 and 70 footcandles for classroom spaces, while the IESNA guidelines for classrooms still use 50-100 footcandles as a guideline (Wu & Ng, 2003). Still, this disagreement is largely overshadowed by other concerns regarding quality and distribution of light, as well as specific issues in daylighting design. Contemporary research and thought regarding lighting in classrooms has largely focused on the need for performance-based standards that accurately represent both illumination and visual comfort metrics. There has been considerable debate about the appropriate metrics for daylighting in particular, as the industry has moved back towards the desire for naturally lit spaces (Mardaljevic et al., 2009).

Research on lighting in classrooms in the past 20 years has also had a significant impact on practice, since a resurgence of findings in the value of natural light have emerged. For example, one study in 1992 looked at cortisol (a hormone) production and concentration abilities in students without access to natural light, and found that natural light was positively correlated with this important hormone (Kuller and Lindsten, 1992). They noted that this research had been re-engaged due to research in the 1980s regarding natural light and recovery times in healthcare environments (Ulrich, 1984). Then in 1999, the Heschong Mahone Group published their oft-cited study on daylighting in classrooms. This study can certainly be credited with having had a significant impact on the industry, as it was one, if not the, major study cited to support the notion that high-performance school buildings can have a positive impact on student learning.

Recent years have seen increasingly convincing studies on the importance of daylighting, hopefully building a more reliable body of literature to support this practice (see Figuero and Rea 2010 for an example of this new research). Still, the major barrier remains that while expert lighting designers and researchers have a sense of what a good visual environment should look like, and how one might measure these lighting and daylighting phenomena, no simple standard has yet been developed to clearly specify the performance standards needed for the industry to respond accordingly. As such, the past two decades have produced many school buildings with sufficient natural light but little attention to issues of visual comfort and glare. Initial research findings are indicating that occupant comfort is often sacrificed in these spaces, but more research is needed to corroborate this finding (Baker, 2010).

6.2.3 Acoustics

Research conducted in the 1980s and 1990s greatly contributed to industry understanding of the necessity of good acoustical conditions in classrooms. These papers, which covered the importance of low background noise level, speech intelligibility and the avoidance of sites with periodic acoustic disruptions (sites near airports, train lines, etc) helped to identify not only that acoustics mattered, but also the appropriate thresholds for acoustical standards (Berg et al., 1996; Crandell & Smaldino, 1995; Evans & Maxwell, 1997).

These studies all contributed to the launching of ANSI Standard 12.60 in 2002, a standard written by the Acoustical Society of America, which has since been adopted into the LEED standards for school buildings and a variety of other related performance standards for buildings (Acoustical Society of America (ASA), 2009; Kurtz et al., 2009). This standard calls for a maximum background noise level of 35 dBa in standard classrooms, with reverberation times between 0.6 and 0.7 seconds, along with guidance and specifications for Sound Transmission Class ratings for exterior and interior wall assemblies, and Impact Insulation Class ratings to address floor-to-floor noise transmission. It is considered to be a very comprehensive standard, and is the first of its kind for any typical building space type (there is no such standard for office buildings, hospitals or other similar spaces, although some of these standards are in development).

7 | 21st Century School Environments: What does the future hold?

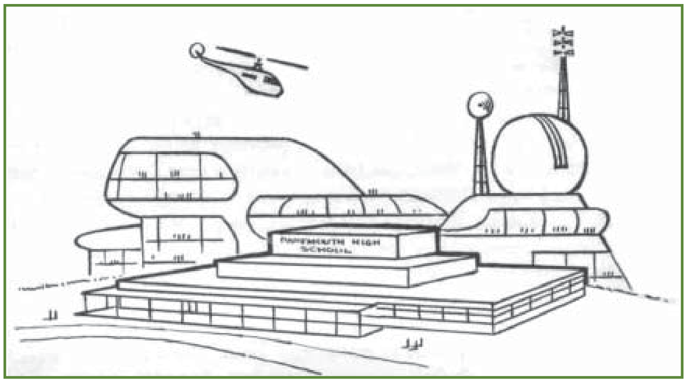


Figure 14. From Castaldi, 1969, an illustration of “Planning for the unforeseeable future”

Every year in the past decade, if not more frequently, one of the more central thought leaders in the school facilities industry will publish an article putting forward the top five, ten, twenty or so of the current and on-the-horizon issues to watch out for. This exercise in visionary thinking often reflects the concerns of the day, along with the heralding of some cool new gadgets and technologies. Just to name a few of these predictions for the future: “privacy niches”, community centers, flexible and ergonomic furniture, distance learning, mobile classrooms, cell phones as learning tools, libraries without books, and schools that look like “Panera Bread” (presumably the restaurant, not the bread itself). These were all taken from a handful of articles from just the past year of School Planning and Management Magazine, a popular trade journal that follows trends in school design. These essays (and their frequency) highlight the uncertainty, excitement, and push for innovation that characterizes the popular press in the school design community. But do they truly attempt to predict the future? Or are they more idealistic visions of the future, similar to the scene depicted in Figure 14 from Basil Castaldi’s 1969 book on school design? And perhaps more importantly, what are the unseen consequences of these new trends? And how thoughtful are we about implementing them? While it is necessary and admirable to look for more innovative ways to provide more stimulating environments for young people, past generations have taught us to endeavor towards unbiased considerations of these new ideas.

However, there is every reason to be excited for what the coming decades may offer, in terms of school design innovations. Information technology is radically changing the ways that we build and conceive of schools, as traditional spatial configurations for presentation are no longer as necessary as they once were, and technologies allow for new learning modes and practices. Major technological advances in energy-related building systems are being made every year, as the sustainable building industry grows and gains acceptance. And as building-related IT systems become more common and energy prices increase, we will hopefully see an increased trend towards more active monitoring of IEQ conditions and energy consumption, in ways that will ultimately lead to better-tuned buildings for energy and comfort. However, if there’s anything we should have learned by now, it’s that new technologies can often solve one set of problems while creating new ones. A reflective, open, and honest design community with robust feedback loops is critical to learning what works well for educational environments.

One way to ensure that we move towards a design paradigm that emphasizes reflection and honest feedback loops is to implement more rigorous standards of practice in school design and operation that are based on performance measurement of buildings and post-occupancy evaluation. For example, the concept of net zero energy buildings requires, by definition, that victory is only declared when a design has successfully produced a building that uses no more energy than it produces in a year (various definitions exist- this is one simple one). There is no need for new high-tech systems, but rather a high level of follow-through, occupant education and communication, and tuning to ensure that systems are functioning as planned. This design target faces a particularly difficult path, however, given that it is a performance goal, rather than something that can be accomplished by the end of the construction phase of a building. Still, ASHRAE code-setting committees have set similar targets for the coming decades, and initial attempts at net-zero buildings (including schools) are showing that these are reachable goals, and ones that we may increasingly find are necessary in our changing global climate.

As a side note, Europe, Australia, and a handful of developed countries have made some significant progress in recent decades in realizing a more progressive vision for 21st century school buildings. Some wonderful examples can be seen in the “Sustainable Schools” report from the Department for Education and Skills in the United Kingdom, or from the database of excellent school facilities available from the OECDs Centre for Effective Learning Environments. There are a number of reasons why the US has not attained as high of levels of innovation achieved in these countries (one major reason is funding policy), but we are fortunate to have these inspirational examples from other places to help move school design forward in the US in coming years.

8 | Conclusion

Every era has had their careful studies of school environments, and every era has had technological innovations, and every era has had the goal of making better, more delightful learning environments for young people. We are neither the first nor the last in this line. In light of this, it may be safest to move forward with caution, looking to post-occupancy evaluation studies to provide holistic and comprehensive feedback on newer design trends. We may also want to look critically at the research findings we rely on today, and question the extent to which they are critically assessing our progress rather than simply supporting the philosophies of the day.

Have school facilities improved in the past century? In some ways, they certainly have. But in other ways, especially in the craft and science of natural lighting and conditioning, we may have simply circled back to where we started. These patterns are largely reflections of the greater societal and technological trends of the 20th century, but they have also represented the sincere dedication of this professional community to improve the quality of learning environments for children in America. We can only hope to continue this dedication with the same fervor in the coming decades.

9 | Works Cited

Acoustical Society of America (ASA). (2009). Acoustical Performance Criteria, Design Requirements and Guidelines for Schools.

Apte, M. G., Hodgson, A. T., Shendell, D. G., Dibartolomeo, D., Hochi, T., Kumar, S. (2002). Energy and indoor environmental quality in relocatable classrooms. Indoor Air, 2002.

ASHRAE. (2010a). ANSI/ASHRAE Standard 55-2010: Thermal Environmental Conditions for Human Occupancy. Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

ASHRAE. (2010b). ANSI/ASHRAE Standard 62.1-2010: Ventilation for Acceptable Indoor Air Quality. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Baker, L. (2010). *What school buildings can teach us: post-occupancy evaluation surveys in K-12 learning environments.* MS Thesis, Department of Architecture, University of California at Berkeley, Berkeley, CA.

Berg, F. S., Blair, J. C., & Benson, P. V. (1996). Classroom acoustics: The problem, impact, and solution. *Language, Speech, and Hearing Services in Schools, 27*(1), 16.

Boice, J. R. (1968). *A History and Evaluation of the School Construction Systems Development Project, 1961-1967.* Menlo Park, CA: Building Systems Information Clearinghouse.

Brager, G., & de Dear, R. (1998). Developing an Adaptive Model of Thermal Comfort and Preference. *ASHRAE Transactions, 104*(SF-98-7-3 (4106) (RP-884)).

Briggs, W. R. (1899). *Modern American School Buildings - Being a Treatise Upon and Designs for the Construction of School Buildings:* J. Wiley & Sons.

Building Research Institute. (1959). *Building illumination: the effect of new lighting levels:* National Academy of Sciences, Natonal Research Council.

Caudill, W. W. (1954). *Toward better school design.* F.W. Dodge Corp.

Castaldi, B. (1969). *Creative Planning of Educational Facilities.* Chicago, IL: Rand McNally & Co.

Chan, T. C. (2009). Do portable classrooms impact teaching and learning? *Journal of Educational Administration, 47*(3), 290-304.

CHPS. (2006). CHPS Best Practices Manual: Volume 3: Criteria. San Francisco, CA: Collaborative for High Performance Schools.

Collins, B. L. (1975). *Windows and people: a literature survey. Psychological reaction to environments with and without windows.* (NBS-BSS-70).

Crandell, C., & Smaldino, J. (1995). Speech perception in the classroom. *Sound-field FM amplification: Theory and practical applications,* 29–48.

Daisey, J. M., Angell, W. J., & Apte, M. G. (2003). Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. *Indoor Air, 13,* 53-64.

Department for Education and Skills. (2006). *Schools for the Future: Design of Sustainable Schools Case Studies.* London.

DOE. (2000). International Performance Measurement & Verification Protocol. Washington, D.C.: U.S. Department of Energy.

Educational Facilities Laboratories Inc. (1970). *The Open Plan School.* Institute for Development of Educational Activities, Inc. Retrieved from http://archone.tamu.edu/crs//.

Erhorn, H., Mroz, T., Morck, O., Schmidt, F., Schoff, L., & Thomsen, K. (2008). The Energy Concept Adviser—A tool to improve energy efficiency in educational buildings. *Energy and Buildings, 40*(4), 419-428.

Evans, G. W., & Maxwell, L. (1997). Chronic noise exposure and reading deficits - The mediating effects of language acquisition. [Article]. *Environment and Behavior, 29*(5), 638-656.

Figueiro, M., & Rea, M. S. (2010). Lack of short-wavelength light during the school day delays dim light melatonin onset (DLMO) in middle school students. *Neuroendocrinology Letters, 31*(1).

GAO. (1995). *School Facilities: Condition of America's Schools.* Washington, DC.

Gray, A. L. (1951). Needed Research in the School-Plant Field. *Review of Educational Research, 21*(1), 63-68.

Griffin, C. W. (1971). *Systems: An Approach to School Construction.* New York, NY: Educational Facilities Laboratories.

Hamlin, A. D. F. (Ed.). (1910). *Modern school houses; being a series of authoritative articles on planning, sanitation, heating and ventilation* (Vol. 1). New York, NY: The Swetland Publishing Co.

Hamon, R. L. (1948). Needed Research in the School-Plant Field. *Review of Educational Research, 18*(1), 5-12.

Hansen, H. L., & Hanssen, S. O. (2002). Education, indoor environment and HVAC solutions in school buildings–consequences of differences in paradigm shifts. *Proceedings of Indoor Air,* 800–806.

Heschong, L., & Mahone, D. (1999). *Daylighting in Schools: An Investigation into the Relationship Between Daylighting and Human Performance.* PG&E.

Hille, T. (2011). *Modern Schools: A Century of Design for Education:* John Wiley & Sons.

Holy, T. C. (1935). Needed Research in the Field of School Buildings and Equipment. *Review of Educational Research, 5*(4), 406-411.

Janssen, J. E. (1999). The history of ventilation and temperature control. *ASHRAE Journal, 41*(10), 48-70.

Kennedy, M. (2003). History in the Making. *American School & University Magazine.* Retrieved from http://asumag.com/mag/university_history_making

Kluttig, H., Erhorn, H., & Morck, O. (2003). IEA ECBCS Annex 36: Retrofitting in educational buildings REDUCE: 25 case study reports from different countries.

Kuller, R., & Lindsten, C. (1992). Health and behavior of children in classrooms with and without windows. *Journal of Environmental Psychology, 12,* 305-317.

Kurtz, A. D., Bruck, D. C., Salter, C., & Lubman, D. (2009). *Leadership in Energy and Environmental Design for Schools-2009 Acoustics Prerequisite and Credit - Evolution and Future Direction.* Paper presented at the 157th Annual Meeting of the Acoustical Society of America.

Kwok, A., & Chun, C. (2003). Thermal comfort in Japanese schools. *Solar Energy, 74*(3), 245-252.

Luce, H. R. (1949). Schools. *Architectural Forum, 91*(4).

Mardaljevic, J., Heschong, L., & Lee, E. (2009). Daylight metrics and energy savings. *Lighting Research and Technology, 41*(3), 261-283.

Marks, J. (2009). *A History of Educational Facilities Laboratories (EFL).* National Clearinghouse for Educational Facilities, 8.

McFeely, J. (2010). *Sustainable Learning Environments (Chartwell School Case Study).* Paper presented at the Center for the Built Environment Industry Partner Meeting, Berkeley, CA.

McGuffey, C. (1982). Facilities. In H. J. Walberg (Ed.), *Improving educational standards and productivity.* Berkeley, CA: McCutchan Publishing.

Mendell, M. J., & Heath, G. A. (2005). Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. *Indoor Air, 15*(1), 27-52.

Mills, W. T. (1915). *American School Building Standards:* Franklin Educational Pub. Co.

Mumovic, D., Palmer, J., Davies, M., Orme, M., Ridley, I., Oreszczyn, T. (2009). Winter indoor air quality, thermal comfort and acoustic performance of newly built secondary schools in England. *Building and Environment, 44*(7), 1466-1477.

National Council on Schoolhouse Construction (Ed.). (1964). *NCSC Guide for Planning School Plants.*

NCSC (Ed.). (1964). *NCSC Guide for Planning School Plants:* National Council on Schoolhouse Construction.

Opportunity Systems Inc. (1983). *An Evaluation of the Institutional Conservation Program.* Washington, DC: US Department of Energy, Office of State and Local Assistance Programs.

Osterhaus, W. K. E. (1993). *Office lighting: a review of 80 years of standards and recommendations.*

Palomera-Arias, R., & Norford, L. K. (2002). *School Energy Use Benchmarking and Monitoring in the West Contra Costa Unified School District.* (HPCBS # E2P21T3c). Sacramento, CA: Submitted to the California Energy Commission, Public Interest Energy Research Program.

Public School Construction Program of Maryland. (2010). *High Performance Building Initiatives in Maryland Public Schools.* Baltimore, MD: Submitted to the Board of Public Works.

Reddy, T., Kissock, J., Katipamula, S., Ruch, D., & Claridge, D. (1994). An Overview of Measured Energy Retrofit Savings Methodologies Developed in the Texas LoanSTAR Program.

Ribéron, J., O'Kelly, P., Maupetit, F., & Robine, E. (2002). Indoor air quality in schools: The impact of ventilation conditions and indoor activities. *Proceedings of Indoor Air,* 109–114.

Roberts, M. (1988, September 12-14). *The Institutional Conservation Program: A Funding Option for Energy Retrofits.* Paper presented at the Fifth Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX.

Schneider, M. (2002). *Do School Facilities Affect Academic Outcomes?* Washington, D.C.: National Clearinghouse for Educational Facilities.

Schrecengost, R. C., Lum, S. K., Notman, J. R., Sattler, D. R., & Heffington, W. M. (1986). Building Energy Use and Conservation in Cycle VIII of the Texas Institutional Conservation Program.

Shendell, D. G., Prill, R., Fisk, W. J., Apte, M. G., Blake, D., & Faulkner, D. (2004). Associations between classroom CO2 concentrations and student attendance in Washington and Idaho. *Indoor Air, 14*(5), 333-341.

Smedje, G., & Norbäck, D. (2000). New ventilation systems at select schools in Sweden–effects on asthma and exposure. *Archives of environmental health, 55*(1).

Tanner, C. K., & Lackney, J. A. (2005). *Educational Facilities Planning:* Pearson Allyn and Bacon

Taylor, A. (2008). *Linking Architecture and Education: Sustainable Design of Learning Environments:* University of New Mexico Press

Turner, C., & Frankel, M. (2008). *Energy Performance of LEED® for New Construction Buildings.* Vancouver, Wash.: New Buildings Institute.

Ulrich, R. S. (1984). View through a Window May Influence Recovery from Surgery. *Science, 224*(4647), 420-421.

US Green Building Council. (2007). LEED (Leadership in Energy and Environmental Design) for Schools, version 2.0. Washington, D.C.

Weisser, A. S. (2006). "Little Red School House, What Now?" Two Centuries of American Public School Architecture. *Journal of Planning History, 5*(3), 196.

Wienstein, C. S. (1979). The Physical Environment of the School: A Review of the Research. *Review of Educational Research, 49*(4), 577-610.

Wirtshafter, R., & Denver, A. (1991). Incentives for energy conservation in schools. *Energy Policy, 19*(5), 480-487.

WSBE. (2005). *Washington High Performance School Buildings: Report to the Legislature.* Washington State Board of Education.

Wu, W., & Ng, E. (2003). A review of the development of daylighting in schools. *Lighting research & technology, 35*(2), 111-125.

Wyon, D., & Wargocki, P. (2007). *Indoor Environmental Effects On The Performance Of School Work By Children.* (1257-TRP). ASHRAE.

Zuraimi, M. S., Tham, K. W., Chew, F. T., & Ooi, P. L. (2007). The effect of ventilation strategies of child care centers on indoor air quality and respiratory health of children in Singapore. *Indoor Air, 17*(4), 317-327.

Acknowledgements/Notes

This paper was initially written as a component of a doctoral qualifying exam, in the Building Science program of the Architecture department at UC Berkeley. The author wishes to thank her committee, Committee Chair Charles C. Benton, and Professors Dr. Gail S. Brager, Dr. Ashok Gadgil, Dr. Deborah McKoy, and Dr. Edward Arens. Thanks also to those who provided feedback on the topic, including Mary Filardo, Barbara Worth, Anisa Baldwin-Metzger, Dr. Glen Earthman, Henry Sanoff, Dr. Matthew Trowbridge, Vivian Loftness and others who attended the Research Summit on Childhood Health and School Buildings. Thanks especially to Judy Marks for her guidance and support with the document. This work was done with the generous support of a STAR Fellowship from the US Environmental Protection Agency. This paper is also available from the author in the form of a simplified poster-size graphic.

